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Soil water depletion under various leguminous cover crops in the derived savanna of West Africa

F.K. Salako[a,*], G. Tian[b]

[a] Department of Soil Science and Agricultural Mechanization, University of Agriculture, PMB 2240, Alabata Road, Abeokuta, Nigeria
[b] Resource and Crop Management Division, International Institute of Tropical Agriculture, Ibadan, Nigeria

Abstract

Leguminous cover crops have the potential of making cropping systems in the tropics sustainable if they would not deplete resources such as soil water and nutrients to the detriment of companion crops. Therefore, a study was carried out at Alabata, Ibadan, southwestern Nigeria, to evaluate the effects of leguminous cover crops on soil water suctions in 1993 and 1994 in order to assess the possibility of integrating them into the farming systems of the savanna zone of West Africa. In 1993, 13 leguminous cover crops (*Aeschynomene histrix*, *Centrosema brasilianum*, *Centrosema pascuorum*, *Chamaecrista rotundifolia*, *Cajanus cajan*, *Crotalaria verrucosa*, *Crotalaria ochroleuca*, *Lablab purpureus*, *Mucuna pruriens*, *Psophocarpus palustris*, *Pseudovigna argentea*, *Pueraria phaseoloides* and *Stylosanthes hamata*) were planted in a randomized complete block design with four replications. Maize and natural fallow (mainly *Chromolaena odorata* and *Imperata cylindrica*) were included as comparisons. Only six of the legumes (*A. histrix*, *C. pascuorum*, *C. cajan*, *C. ochroleuca*, *M. pruriens*, and *P. phaseoloides*) were included in the measurements in the 1994 new plots. Soil water suctions at various stages of legume growth were measured at daily or weekly intervals (depending on the frequency of rainfall events) using tensiometers installed at 0–15 and 15–30 cm soil depths. Soil water suctions exceeding 10 kPa (theoretical field capacity) were observed mainly between 6 and 12 weeks after planting (WAP), and by 20 WAP when cover crops had matured and rainfall frequency was very low. Soil water suctions were significantly related ($r^2 > 0.80$) to dry matter between 8 and 10 WAP. The studied cover crops were classified in three groups which can be used as a guide for choosing the legumes in tropical farming systems. Soil water depletion was markedly influenced by growth characteristics of legumes and distribution of rainfall during the rainy season. Leguminous cover crops conserved soil water after their growth needs were satisfied.

Keywords: Legumes; Soil water; Suction; Alfisol; Southwestern Nigeria

1. Introduction

When leguminous cover crops are integrated into cropping systems, they are usually expected to enhance nutrient availability for companion crops. They are known to promote efficient utilization of soil and fertilizer nutrients and make direct contributions to improve soil nutrient content (Carsky et al., 1999). Tropical climates are highly variable and multiple cropping systems are common (Jackson, 1989). A wide variety of legumes are potentially useful for legume-based cropping technologies. Weber (1996) suggested that research needs to be shifted towards developing a basket of prototype technologies which match the diversity of target conditions in farmers' fields. Tarawali et al. (1999) have described the performance of various forage legumes tested in the subhumid region of Nigeria, and recommended multiple cropping practices,

* Corresponding author.
E-mail addresses: kfsalako@yahoo.ie, kolawolesalako@hotmail.com (F.K. Salako).

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such as legume–legume or legume–maize mixtures, as profitable investments. Obiagwu (1997a,b) emphasized the need to screen leguminous cover crops for their genetic ability to overcome physical and environmental constraints before their introduction into the farming systems of the savanna regions of Nigeria.

Water is a major consideration for crop production in the tropics where most agriculture is rainfed (Rachie, 1978; Jackson, 1989). In the savanna region, dry spells in the rainy season could inhibit the good performance of crops even when the overall amount of rainfall is adequate (Jackson, 1989). Armstrong et al. (1999) found that in Queensland, Australia, annual legumes grew faster and exhausted soil water more rapidly than perennials, but that the perennials were inefficient in converting small to moderate rainfall (25–50 mm) into dry matter production. Astatke et al. (1995) reported that within 0–100 cm depth of a Vertisol in Ethiopia, deep-rooted *Lablab purpureus* and cowpea depleted greater amounts of available soil water during the growing season than vetch and clover. Soil water dynamics under legume cover crops must be understood in order to estimate their crop water requirements (Doorenbos and Pruitt, 1977) when incorporated into the farming systems in the tropics. In the savanna region of West Africa, there have been few studies focused on evaluating the water requirements during growth of a wide range of cover crops. The usual assumption is that water would not be limiting if rainfall amount is adequate (>1000 mm). However, this may not be so when dry spells occur under multiple cropping systems or when a particular legume has a high demand for water during growth.

Therefore, this study was conducted in order to determine fluctuations in soil water during different growth stages of various leguminous cover crops. Based on this evaluation, the leguminous cover crops were classified for potential integration into the multiple cropping systems in the savanna zone of West Africa.

2. Materials and methods

2.1. Description of the study area

This study was carried out at Alabata village, about 20 km north from the International Institute of Tropical Agriculture (IITA), Ibadan (latitude 7°30′N and longitude 3°54′), southwestern Nigeria. Mean annual rainfall was 1308 mm in 1993 and 1064 mm in 1994 (Fig. 1), and the mean is 1300 mm. Annual pan evaporation was 1468 mm in 1993 and 1417 mm in 1994. Although the rainy season at the site is usually between March and November, only July, September and October had substantially higher rainfall than evaporation or potential evapotranspiration in 1993 and 1994 (Fig. 1). Rainfall in August is usually less than in July and September because of the bimodal distribution of annual rainfall.

At the experimental site, soil particle size distribution for the topsoil (approximately 0–24 cm depth) was 810 g kg^{-1} sand, 130 g kg^{-1} silt, and 60 g kg^{-1} clay (G.E. Akinbola, G. Tian, F.K. Salako, unpublished data). Gravel contents were between 65 and 203 g kg^{-1} between 0 and 35 cm depth while available water content was about 0.07 $m^3\,m^{-3}$. The soil was classified as a Typic Haplustalf.

2.2. Experimental establishment

A randomized complete block design with four replications was used in this trial. Leguminous cover crops as treatments included *Centrosema brasilianum*, *Centrosema pascuorum*, *Chamaecrista rotundifolia*, *L. purpureus*, *Psophocarpus palustris*, *Pseudovigna argentea*, *Mucuna pruriens*, and *Pueraria phaseoloides* (spreading legumes), *Stylosanthes hamata*, *Crotalaria verrucosa*, *Crotalaria ochroleuca*, *Aeschynomene histrix* (erect legumes), and *Cajanus cajan* (shrub). Natural fallow plots with *Imperata cylindrica* and *Chromolaena odorata* were included for comparison. The plot size was 8 m × 12 m in 1993 and 8 m × 6 m in 1994. The legumes were planted in June 1993 and 1994 on different plots at the site. Seven kg of P ha^{-1} (single superphosphate) and 25 kg K ha^{-1} (potassium chloride) were applied at the time the legumes were planted.

2.3. Measurement of soil water dynamics under legumes

Soil water suction was monitored at 15 and 30 cm depths in the field with vacuum gauge tensiometers (Cassell and Klute, 1986) during the rainy seasons

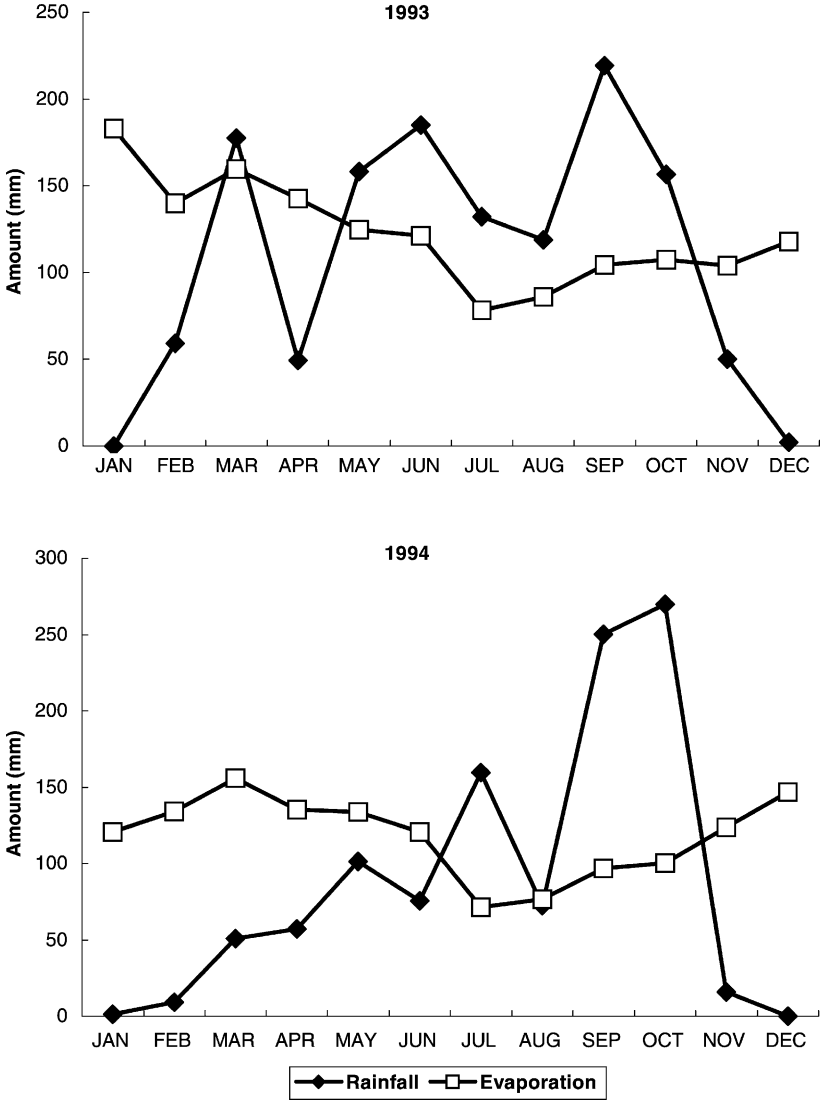

Fig. 1. Rainfall and pan evaporation in Ibadan (near Alabata), southwestern Nigeria in 1993 and 1994 (source: data were collected from the Crop Modeling Unit, Resource and Crop Management Division, IITA, Ibadan, Nigeria.

(between June and November) of 1993 and 1994. There was a single tensiometer at each depth. Observations on soil water were made only for the middle two replications due to the limited numbers of tensiometers. Measurements in 1994 were made on fewer species and for a longer period than 1993. This decision was based on the preliminary evaluation of the 1993 data for more sensitive measurements in 1994. Tensiometer readings were carried out at daily to weekly intervals, depending on the frequency of rainfall. Failure of any tensiometer during the dry spells implied that a reading of 80 kPa (highest possible reading in literature) would be assigned to the treatment. Soil water contents were determined gravimetrically and were converted to volumetric water contents from soil bulk densities. The dry aboveground biomass (dry matter yield) was measured at different growth stages.

2.4. Data analysis and cover crop classification

The mixed model procedures of the SAS® system (Littell et al., 1996) were used for statistical analysis. In order to classify the cover crops, 10 kPa was assumed to be soil water suction at field capacity for the sandy soil (Lal, 1979). Furthermore, the PROC GLM of SAS (LSD and DUNCAN options) was used to group the legumes from 1993. Three categories were established at different growth stages for the legumes: high, intermediate, and low water demand. Simple linear regression analyses were carried out with and without logarithmic ($\log_{10}$) transformations.

3. Results

3.1. Soil water dynamics in the 1993 rainy season

In 1993, suctions exceeding 10 kPa were observed mainly between 6 and 12 weeks after planting (WAP) (Fig. 2). At 6 and 10 WAP, *L. purpureus* and *M. pruriens* had about 30 kPa suction at 15 and 30 cm depths. Also, at 6 WAP, *P. palustris* and maize plots exceeded 10 kPa, and at 10 WAP the natural fallow of *I. cylindrica*, *P. argentea*, and maize plots exceeded 10 kPa. Cover crop and depth interaction was usually significant at 15 cm depth. Differences were also found between depths 15 and 30 cm. Cover crops such as *L. purpureus* and *M. pruriens* were significantly different from others, irrespective of depth. Soil water content ranged between 0.06 and 0.44 $m^3\,m^{-3}$ during the growth stages.

The dry matter yields of the erect legumes in the order of *C. cajan* (7405 $kg\,ha^{-1}$), *C. ochroleuca* (3688 $kg\,ha^{-1}$) exceeded the highest yields for herbaceous legumes (*L. purpureus* (3610 $kg\,ha^{-1}$) and *M. pruriens* (3206 $kg\,ha^{-1}$)) at 16 WAP. Soil water suction was significantly related to aboveground dry matter at different growth stages of the cover crops except at 14 WAP (Table 1). The cover crops which caused relatively high soil water suctions before 10 WAP (Fig. 2) were *M. pruriens* and *L. pupureus* (with broad leaves, rapid dry matter accumulation and canopy development). *M. pruriens* consistently had the highest ground coverage from 6 to 16 WAP followed by *L. purpureus* which had 92–100% coverage between 10 and 16 WAP. By 16 WAP, *P. palustris*, *C. pascuorum* and *C. cajan* had ≥95% coverage.

Table 1
Simple linear regression showing relationships between soil (0–30 cm depth) suction (kPa; dependent variable, *Y*) and aboveground dry matter ($kg\,ha^{-1}$; independent variable, *X*) in 1993[a]

Type	WAP	*a*	*b*	r^2	*P*	*n*
log–log	6–16	1.26	−0.21	0.17	0.001	62
Linear	6	7.38	0.04	0.74	0.001	13
Linear	8	1.61	0.02	0.84	0.001	12
Linear	10	4.53	0.01	0.81	0.001	13
log–log	14	0.93	−0.19	0.06	0.224	12
log–log	16	1.97	−0.47	0.37	0.016	13

[a] WAP: weeks after planting; *a*: intercept of regression line; *b*: slope of regression line; r^2: coefficient of determination; *P*: probability level of significance; *n*: number of *X* or *Y* variable; log–log: transformed data ($\log_{10}$ (*Y* and *X*)); linear: untransformed data.

Maize, *P. phaseoloides*, and *C. ochroleuca* were classified as crops with intermediate soil water demand (Table 2). The classification re-emphasized that *M. pruriens* and *L. purpureus* would have high water demand (Fig. 2) because of rapid growth. *S. hamata* and *A. histrix* (erect legume) and *P. palustris* caused high soil water suction. The dry matter yield of *S. hamata* at 16 WAP was 391 $kg\,ha^{-1}$; *P. palustris* had 1285 $kg\,ha^{-1}$, and *A. histrix* had 660 $kg\,ha^{-1}$. *C. cajan*, a shrub, with the highest dry matter yield of 7405 $kg\,ha^{-1}$ at 16 WAP was relatively low in water demand at the early growth stage, and maintained a moderate suction at specified maturity, although by nature it would keep growing beyond the period to about 2 or 3 years. *Imperata cylindica* was relatively high in water demand at the mature stage.

3.2. Soil water dynamics at the onset of dry season in 1994

Soil water suctions were less than 10 kPa between 12 and 20 WAP. Daily measurements between 20 and 23 WAP showed that the plots with cover crops still had soil water suction less than 10 kPa (Fig. 3). However, the harvested maize (ex-maize) plot maintained a significantly higher soil water suction than cover crop plots, especially at 15 cm depth during the period. By 23 WAP (163 DAP), soil water suctions (averaged for 15 and 30 cm depths) ranged between

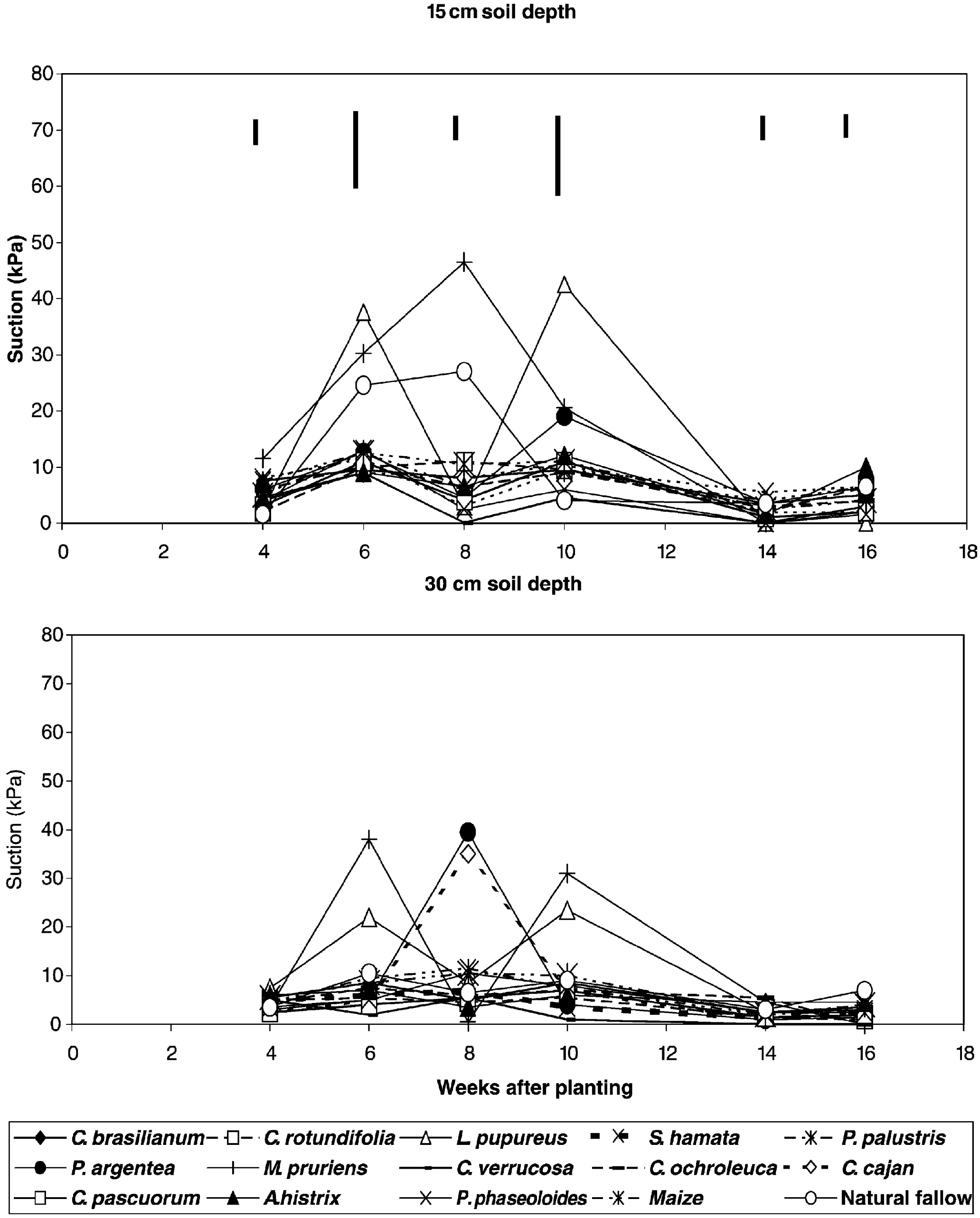

Fig. 2. Soil water suction at 15 and 30 cm depth at different growth stages of cover crops in 1993 at Alabata: LSD bars (vertical bars) are for interactions of cover crop with depth.

11 kPa (natural fallow) and 52 kPa (*C. pascuorum*). *M. pruriens* (30 cm depth) plot had a soil water suction of 9 kPa while *C. pascuorum* (15 cm depth) had 76 kPa. Soil water suctions for *C. pascuorum*, *C. ochroleuca*, and *A. histrix* were significantly higher than those for *C. cajan*, *M. pruriens*, and natural fallow. The 15 cm depth had a significantly higher suction (46 kPa) than the 30 cm depth (21 kPa) (LSD(0.05) $=$ 10). From

Table 2
Classification of cover crops and maize according to relative soil water suctions at different growth stages in 1993[a]

Growth stage	Soil water suction class	Cover crops
Early/intermediate (≤10 WAP)	High	*M. pruriens* *L. purpureus*
	Intermediate	*C. brasilianum* *P. palustris* *P. phaseoloides* *C. ochroleuca* *I. cylindrica* Maize
	Low	*C. verrucosa* *C. rotundifolia* *S. hamata* *P. argentea* *C. cajan* *A. histrix* *C. pascuorum*
Matured (>10 WAP)	High	*S. hamata* *P. palustris* *A. histrix* *I. cylindrica*
	Intermediate	*C. brasilianum* *C. rotundifolia* *P. argentea* *M. pruriens* *C. ochroleuca* *C. pascuorum* *C. cajan* *P. phaseoloides* Maize
	Low	*L. purpureus* *C. verrucosa*

[a] High, intermediate or low suction was obtained using the range of suctions observed at each growth stage and the Duncan's multiple range test as guide. Thus, a high value at one stage may be a low value at another stage since it is the relative grouping of legume that was the focus.

143 to 164 DAP, soil water suctions were high in *C. pascuorum*, *C. ochroleuca*, *A. histrix*, and ex-maize plots, intermediate in *P. phaseoloides* and *C. cajan* plots, and low in *M. pruriens* and natural fallow plots.

High soil water suctions (Figs. 2 and 3) were observed in plots with *A. histrix*, *S. hamata*, *P. palustris*, *C. pascuorum*, and *C. ochroleuca* at maturity (between 10 and 23 WAP). Cover crops which had a relatively low water demand up to 10 WAP were *C. verrucosa*, *C. rotundifolia*, *S. hamata*, *P. argentea*, *C. cajan*, *A. histrix*, and *C. pascuorum*. Maize was classified as intermediate in water demand with legumes such as *C. brasilianum*, *P. palustris*, and *C. ochroleuca* up to 10 WAP. Between 10 and 16 WAP, legumes which had intermediate water demand were *C. brasilianum*, *C. rotundifolia*, *P. argentea*, *M. pruriens*, *C. ochroleuca*, *C. pascuorum*, *C. cajan*, and *P. phaseoloides* (Table 2).

4. Discussion

4.1. Soil water suctions in relation to rainfall

Although this study was largely carried out when rainfall was adequate, there were critical periods of limiting soil water supply as observed in August, and October/November of 1993 and 1994 (Fig. 1). Based on the approach in this study, the suctions above 80 kPa were not adequately accounted quantitatively. Therefore, the results were only indicative of relative soil water depletion among species. The annuals among the cover crops were mature by October but the semi-perennials such as *C. cajan* would still grow into the dry season. There was water stress in August and November 1993 and 1994 because the climatic conditions were more variable in August and November than in the other months due to the inconsistent rainfall pattern or distribution. Such variability would affect soil water dynamics (Jackson, 1989), and it is in this context that the classification in Table 2 has to be considered with regard to the rainfall pattern of 1993 (Fig. 1) when the data were collected.

4.2. Effect of growth characteristics of cover crops

Soil water suctions of the spreading leguminous cover crops were higher than those of the erect types because they used more water and grew more rapidly. It was observed that *M. pruriens* and *L. purpureus* conformed to the general observation that spreading legumes increased soil water suctions earlier than erect legumes. However, *P. argentea* did not conform. Six WAP, dry matter accumulation (Table 1) influenced soil water suction significantly, and such influence diminished from 14 WAP. Erect legumes such as *A. histrix*, *C. pascuorum*, and *Crotalari*a species had high soil water suctions, whereas a shrub such as *C. cajan*

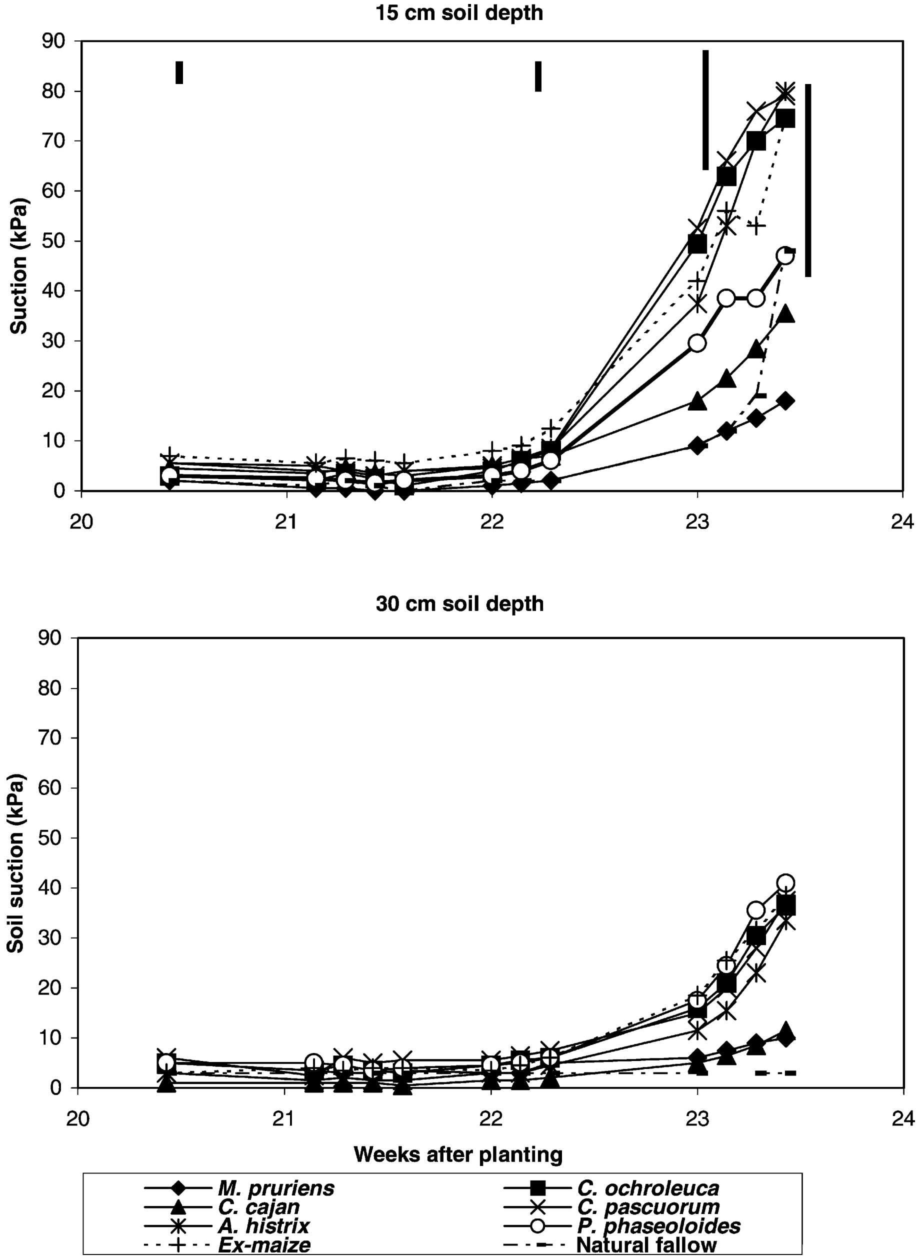

Fig. 3. Soil water suction at 15 and 30 cm depth at different growth stages of cover crops in 1994 at Alabata: LSD bars (vertical bars) are for interactions of cover crop with depth.

was moderate because it would need soil water for a longer period than other legumes. Soil water (and nutrient) movement is influenced by soil water suction (Jury et al., 1991; Miyazaki, 1993).

A legume such as *C. cajan* would accumulate more biomass than the at the end of its growth cycle than the spreading legumes in 1 year. However, the cumulative biomass of the spreading legumes in about 3 years of

C. cajan growth could also be almost equivalent to that of *C. cajan*. Armstrong et al. (1999) stated that perennials would extract soil water more slowly than the annual legumes and were inefficient at converting small to moderate amount of rainfall (20–50 mm) into dry matter.

4.3. Implications

Multiple cropping is a common practice in the tropics (Norman et al., 1995), and this is even reflected in the recommendations of legume mixtures as forages in the derived savanna (Tarawali et al., 1999). The classification of the cover crops in this study could serve as a guide for the choice of particular cover crops to meet various objectives that could necessitate their use. Crop water requirements of different cover crops can be assessed by their soil water suction classes. This study showed that some legumes depleted soil water more than the others during growth with the differences among legumes becoming pronounced during dry spells.

5. Conclusion

This study showed that soil water suctions were influenced by growth characteristics of leguminous cover crops and the distribution pattern of rainfall. Depending on the stage of growth, legumes had low, moderate, and high water demand. Leguminous cover crops conserved soil water after their growth needs were satisfied.

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